3-5 Application of satellite and UAVSAR radar to volcanoes

Lundgren, Paul

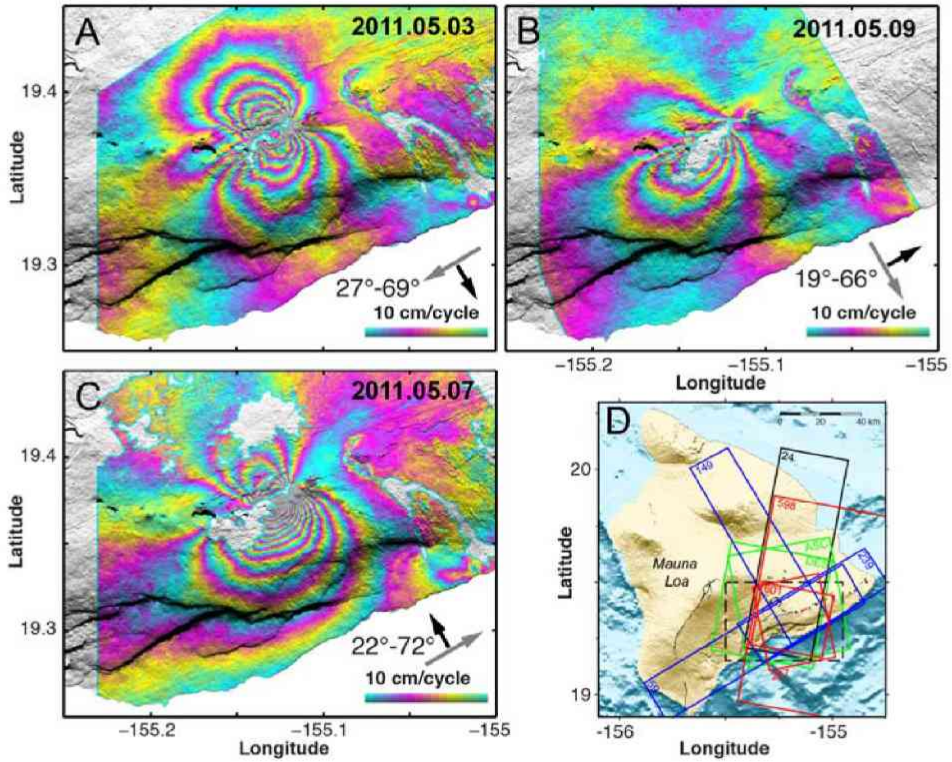
3-5

Application of satellite and UAVSAR radar to volcanoes

Paul Lundgren, Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109, USA

Surface deformation measurements represent one of the key types of measurements for understanding volcanic processes and hazard. Surface deformation of volcanoes often precedes other signs of renewed volcanic activity and in some cases this new deformation occurs without leading to an immediate eruption. In other cases new deformation can precede an eruption on time scales of months to hours, depending on the scale and mechanism of eruption. A significant limitation of current satellite based SAR systems is their relatively long repeat intervals. Immediately before volcanic eruptions deformation may evolve over time scales significantly shorter than the repeat interval, and despite the relatively shorter repeat intervals of today's newer satellite systems (i.e. TerraSAR-X, COSMO-SkyMed), the limited access by scientists to these data greatly limits their scientific and hazard mitigation value.

UAVSAR, an airplane based SAR system, provides a measurement system that can complement satellite based observations by providing rapid revisits and flexible imaging directions of active volcanoes to better understand their pre-eruption deformation and for better hazard mitigation. UAVSAR observations were since 2009 on an annual basis for volcanoes in the U.S. (including Alaska, and Hawaii) and Central America (2010, 2011). Starting in 2012 we will be expanding geographic coverage to include Japan and South America. The first flights in Japan and South America are expected in August 2012 and early 2013, respectively. We pla to repeat UAVSAR flights annually, unless a significant change in volcanic activity occurs that warrants a volcanic eruption response.



UAVSAR unwrapped interferograms (displ ayed at 10 cm color cycle wrap) spanning the March 20 11 Kamoamoa, Kilauea Volcano, Hawaii,fissure eruption. Each interferogram is ~1.4 years in time separation (January 2010 – May 201 1). Different viewing dir ections (black arrows) with ground incidence angles (~20-70°) from three different aircraft flight directions (gray arrows) give significantly different surface deformation patterns. The map (D) gives the location of Kilauea within the dashed area (note that interferograms in A-C are from an area smaller than the dashed box). UAVSAR data coverage areas for the three interferograms are shown by the blue rectangles in (D).

Application of satellite and UAVSAR radar interferometry to volcanoes

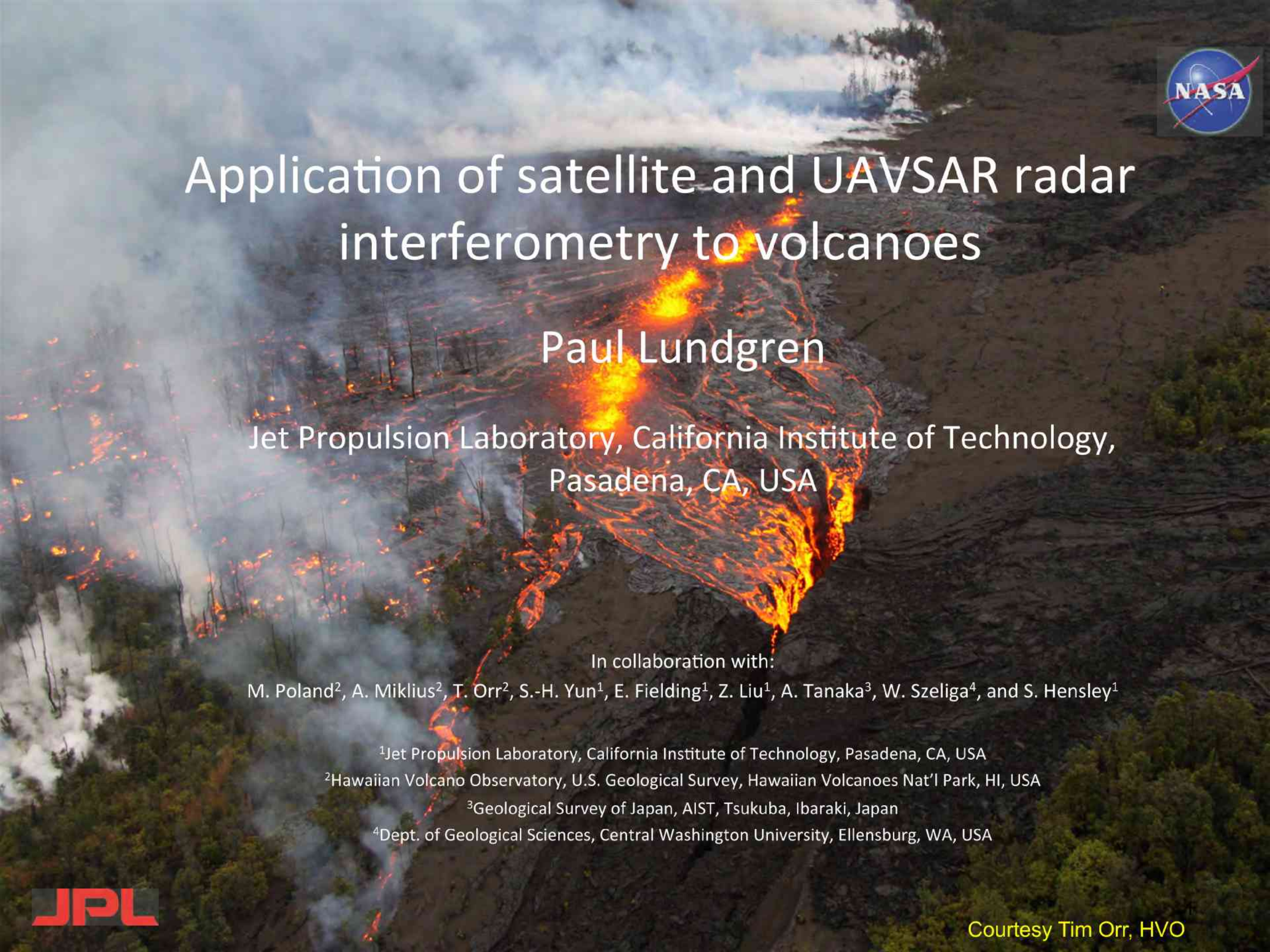
Paul Lundgren

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

In collaboration with:

M. Poland[2], A. Miklius[2], T. Orr[2], S.-H. Yun[1], E. Fielding[1], Z. Liu[1], A. Tanaka[3], W. Szeliga[4], and S. Hensley[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
[2]Hawaiian Volcano Observatory, U.S. Geological Survey, Hawaiian Volcanoes Nat'l Park, HI, USA
[3]Geological Survey of Japan, AIST, Tsukuba, Ibaraki, Japan
[4]Dept. of Geological Sciences, Central Washington University, Ellensburg, WA, USA



Courtesy Tim Orr, HVO

Outline

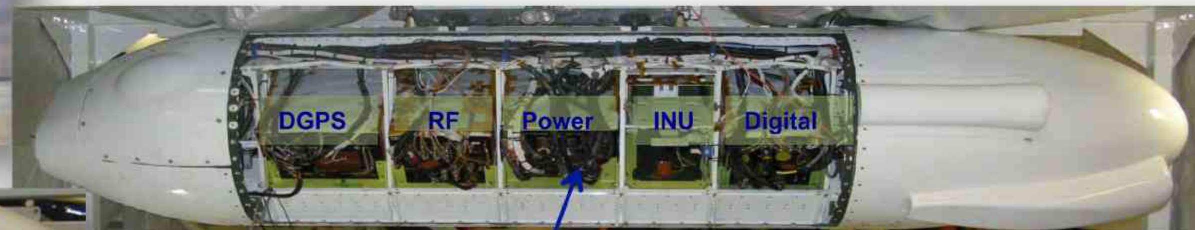
- Overview of UAVSAR and UAVSAR Volcanoes project
- Example for the 2011 Kilauea fissure eruption

UAVSAR Volcanoes Objectives

- Understand volcano eruption processes over time scales of years to sub-daily
  - Use surface deformation observations from InSAR (satellite and UAVSAR) and GPS (and other in-situ) to constrain volcano source models
  - Develop dynamic source models to better understand non-linear eruption processes
- Develop UAVSAR as a volcano response tool

UAVSAR Overview

- UAVSAR was developed under NASA ESTO funding to support repeat-pass radar interferometry and was designed to also serve as a radar technology test bed.
- Instrument in the non-pressurized pod is compact, modular, and adaptable to support multiple airborne platforms and frequency upgrades.



Electronics bay common to all frequencies

Frequency-specific antenna bay

Capabilities in Science Demonstration Since 2009

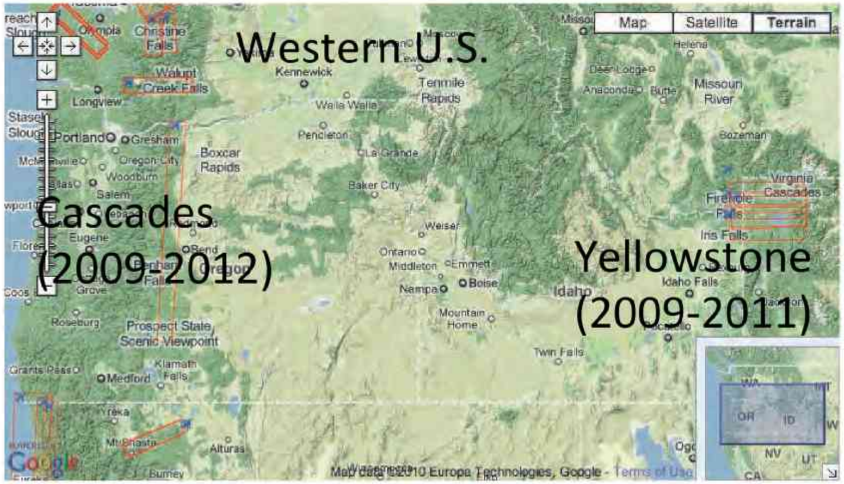
- L-band repeat-pass polarimetric interferometry enabled by electronically scanned antenna and precision autopilot that can repeat tracks to within a 5 m tube.
- Applications include surface deformation for solid earth, cryospheric studies, vegetation mapping and land use classification, archeological research, soil moisture mapping, geology and cold land processes.

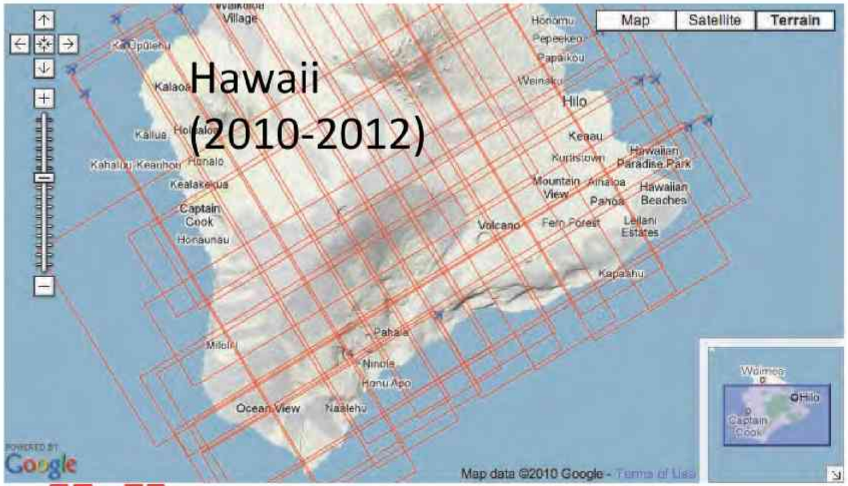
UAVSAR/G-III Operational Parameters

Parameter	Value
Frequency	L-Band 1217.5 to 1297.5 MHz
Bandwidth	80 MHz
Intrinsic Resolution	1.8 m Slant Range, 0.8 m Azimuth
Polarization	Full Quad-Polarization
Nominal Altitude	12,500 m (41,000 ft)
Nominal Ground Speed	215 m/s
Nominal Spatial Posting	6 m
Nominal Range Swath	22 km (POLSAR), 18 km (RPI)
Look Angle Range	25^{o} - 65^{o}
Noise Equivalent σ^{o}	< -50 dB

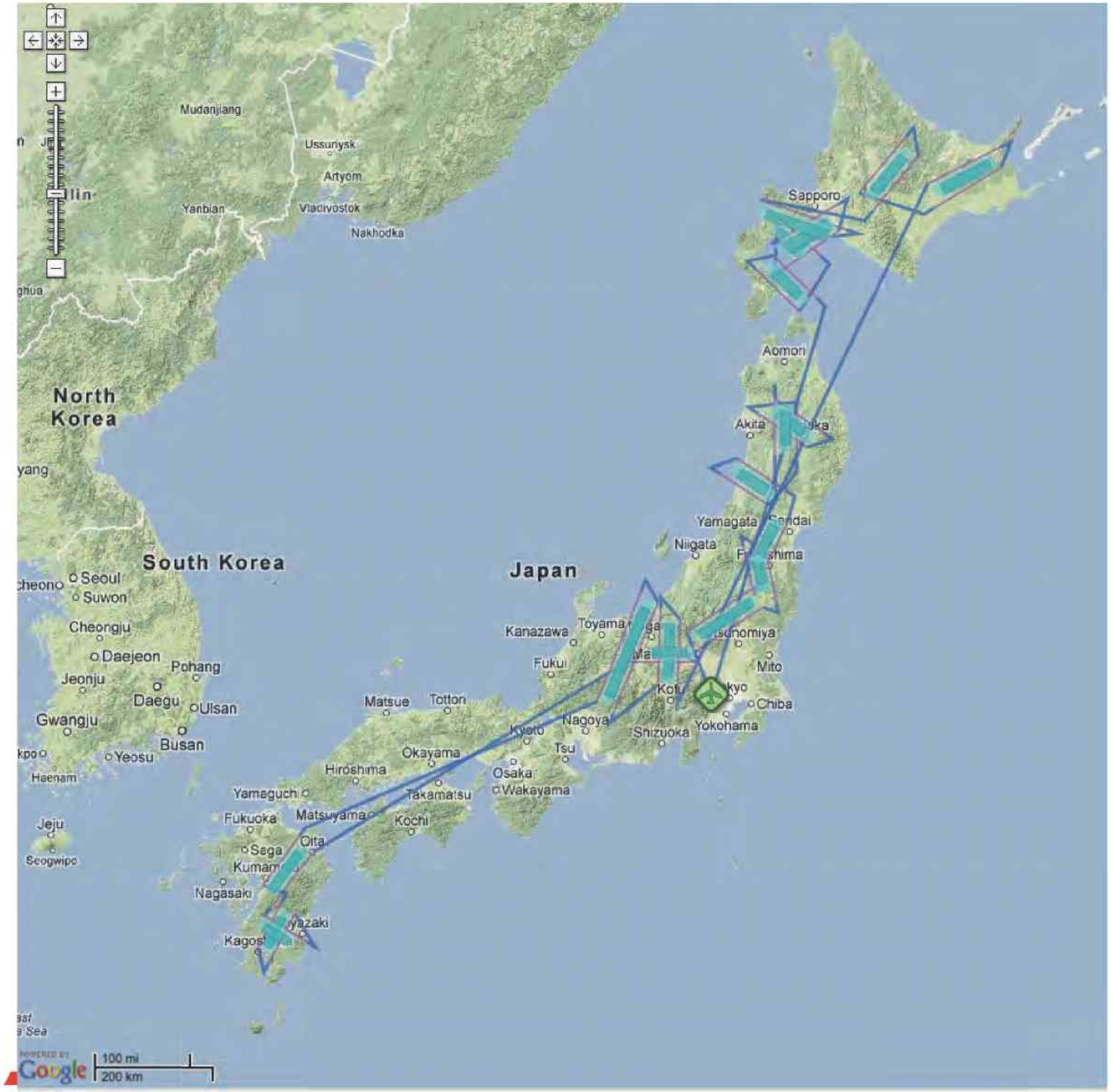
UAVSAR Volcanoes (2009-2011)

UAVSAR acquired under 1st phase of funding (2009-2011)



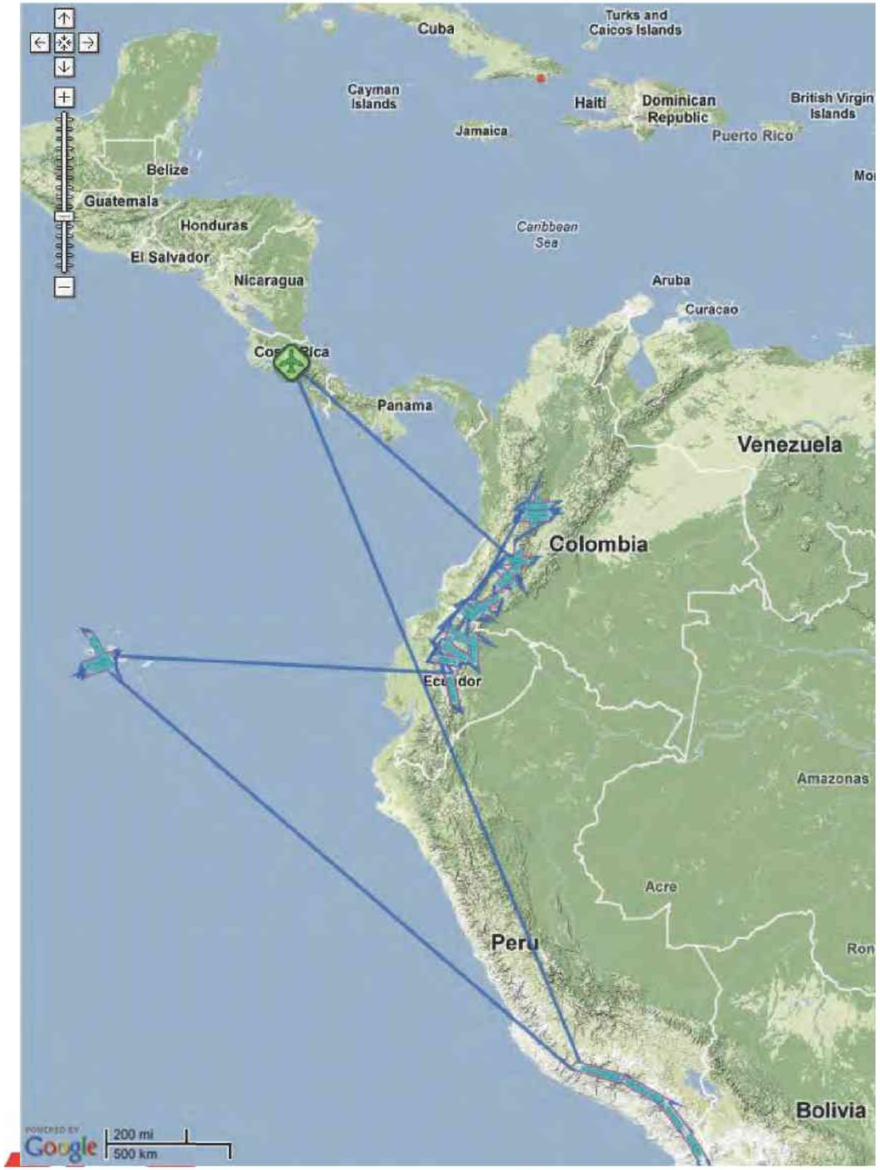


Proposed Volcano Flight Plans in Japan

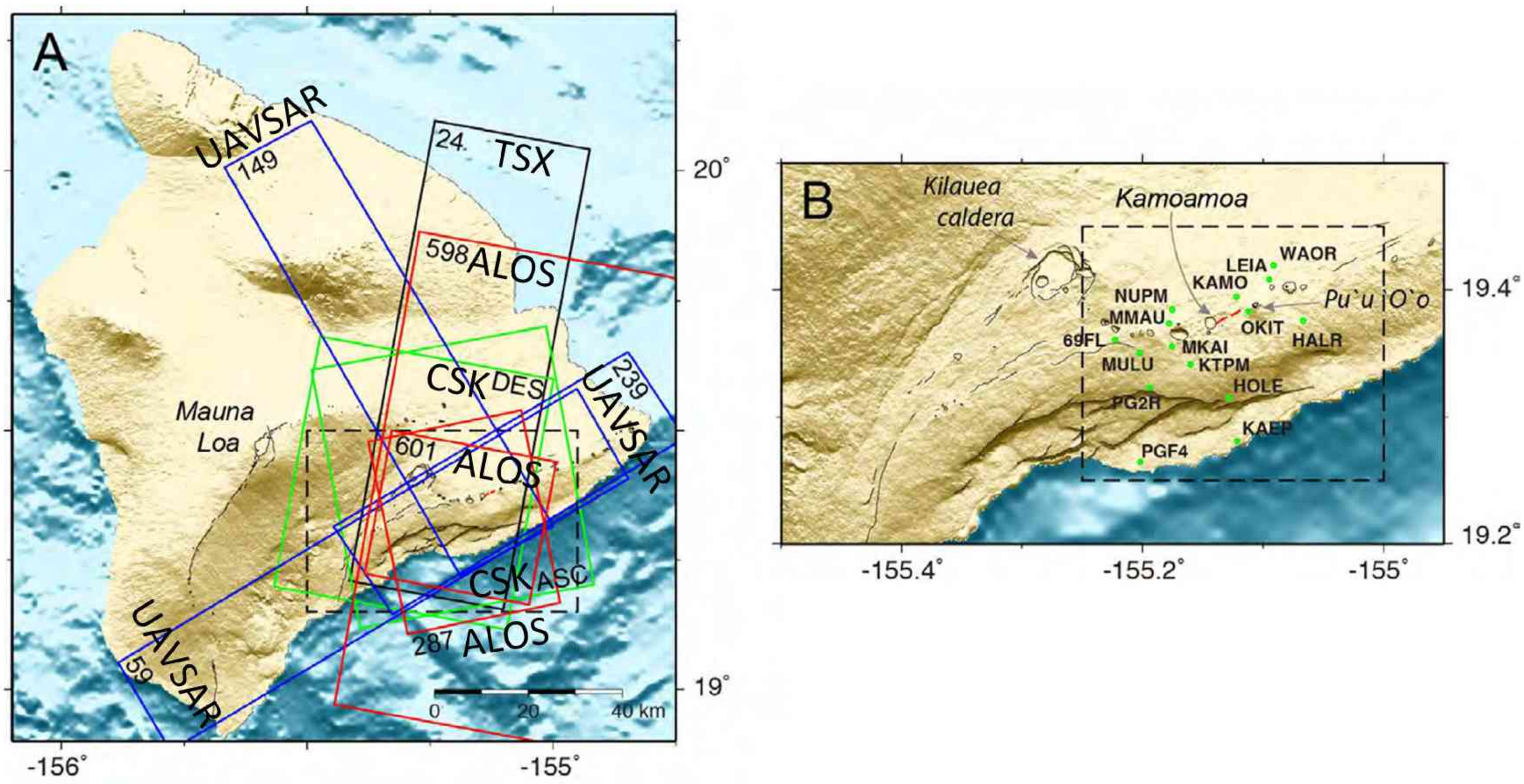


- Volcanoes will be imaged from opposite flight directions in most cases (some will also be flown at 90° for ~3D resolution)
- Repeat interval 1 year
- Possibility to return earlier in case of significant precursory evidence for a future volcano eruption

South America 2013



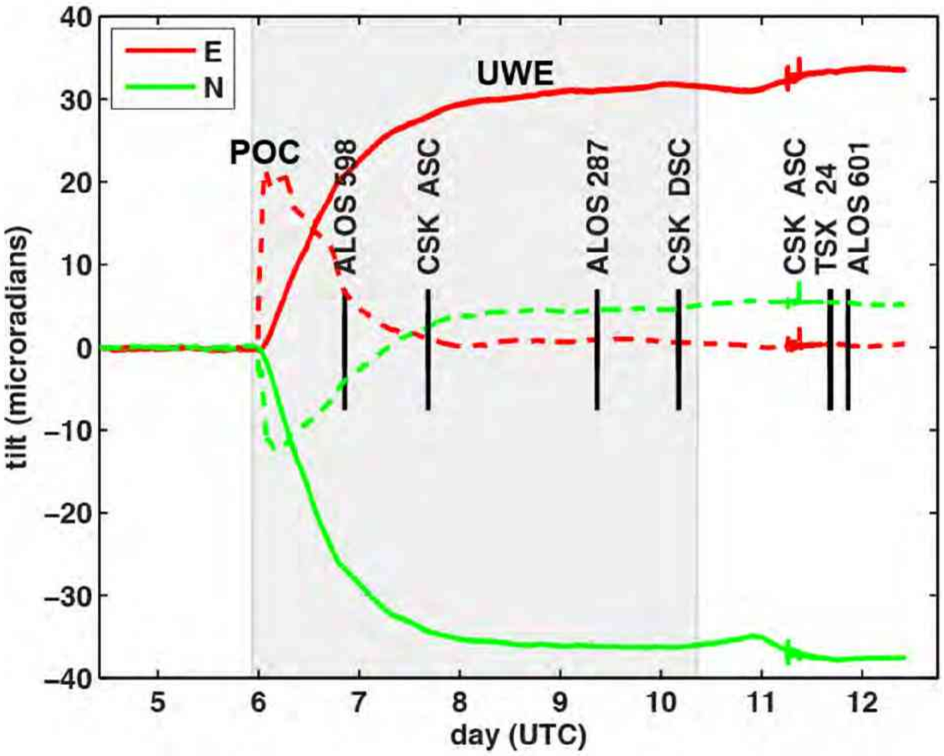
Kilauea, Hawaii



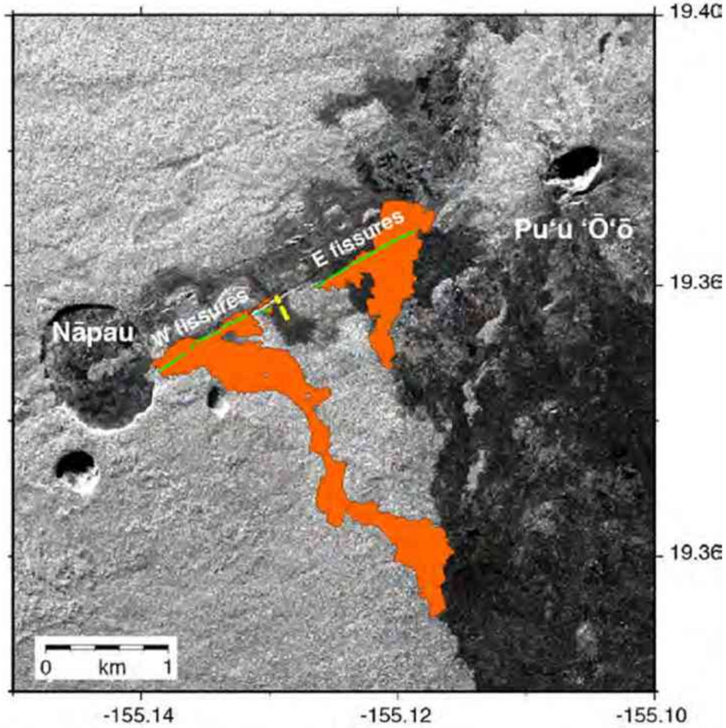
Hawaii InSAR tracks (A) and (B) Kilauea/E Rift focus area around Kamoamoa eruption (fissures in red, courtesy T. Orr, HVO, GPS sites green dots)

March 5-9, 2011 Kamoamoa Eruption

Kilauea summit (UWE)
and Pu'u O'o (POC) tilt

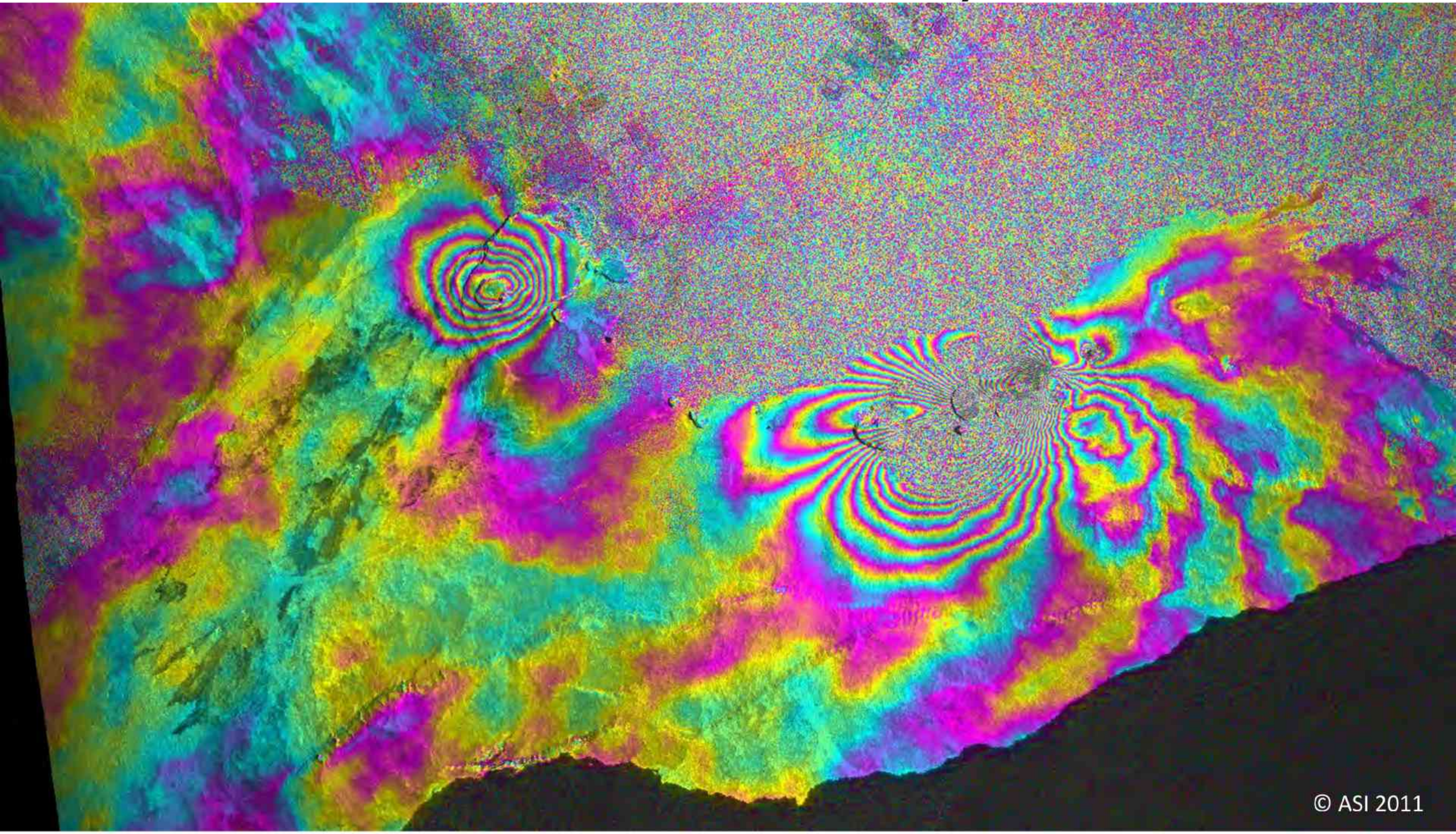


ERZ Fissure eruption



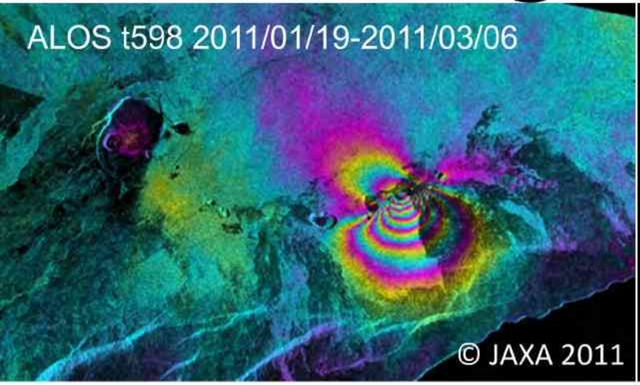
Eruption started late afternoon March 5 (HST) with Pu`u `O`o tilt (deflation) starting 30 min prior to Kilauea tilt (deflation)

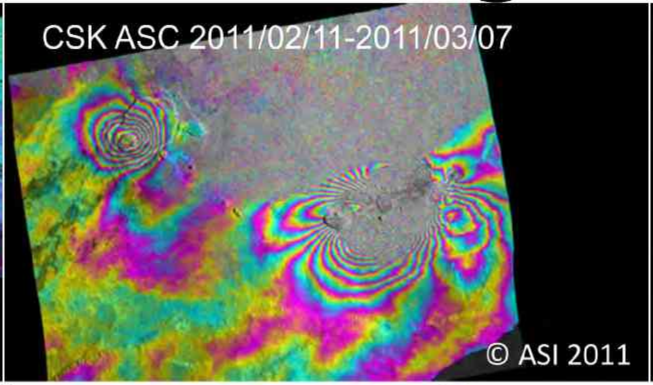
Near-real time COSMO-SkyMed data

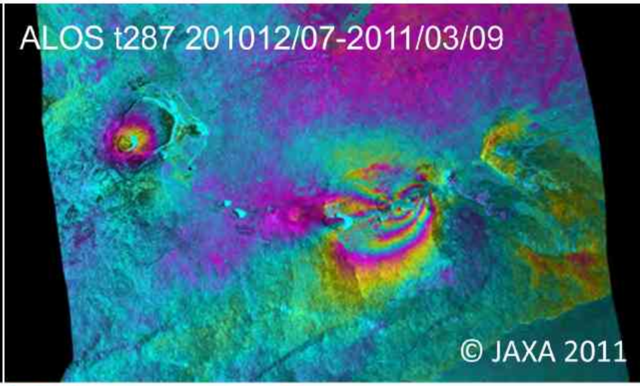


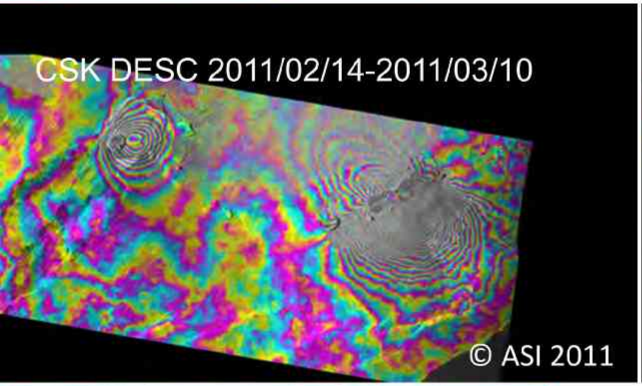
1st interferogram on March 7, ~12 hrs after acquisition

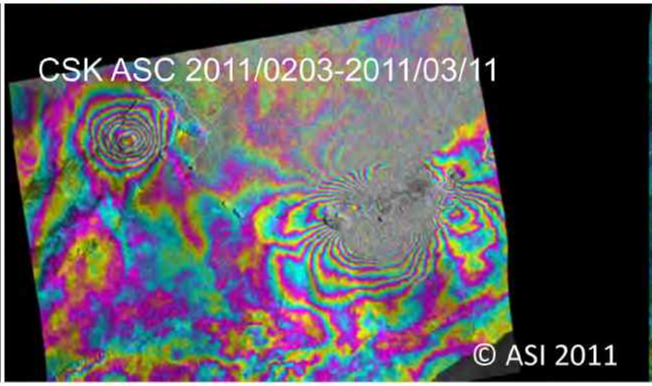
Interferograms ending March 6-11

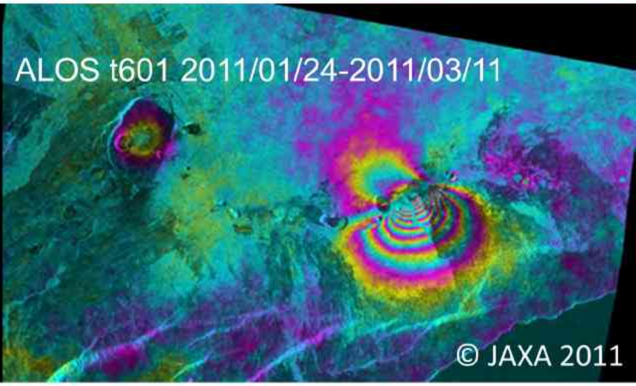


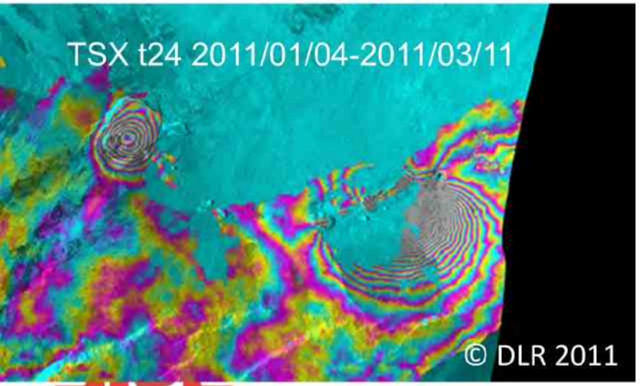




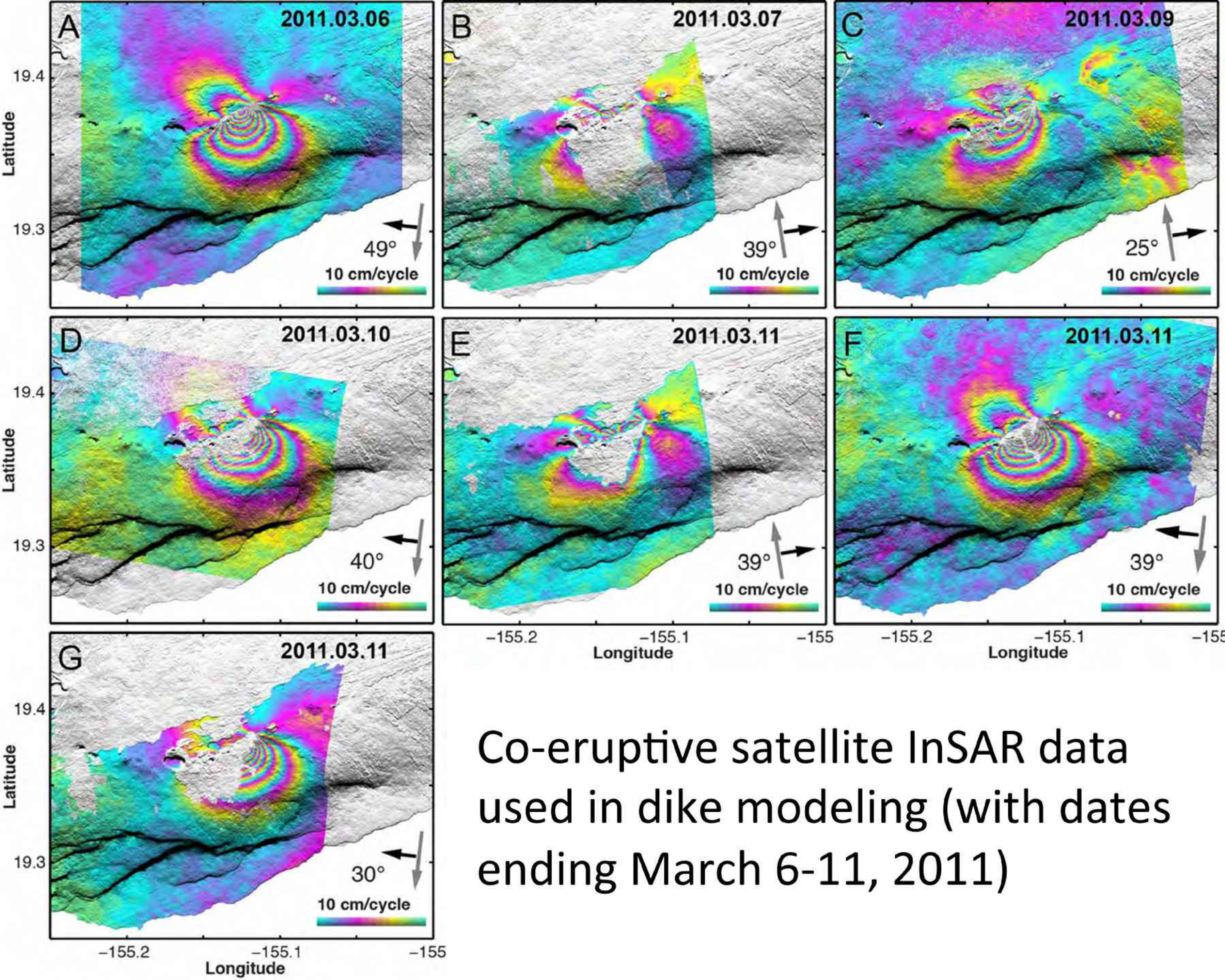






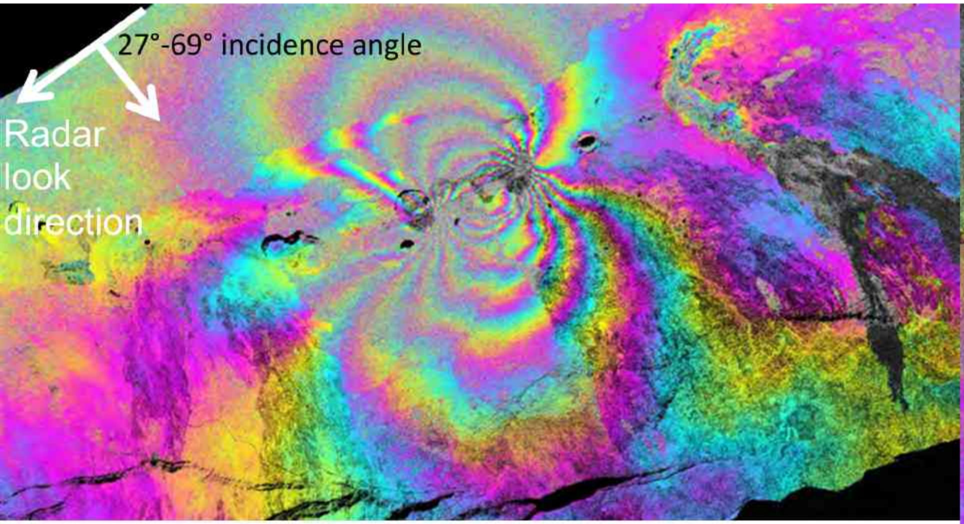


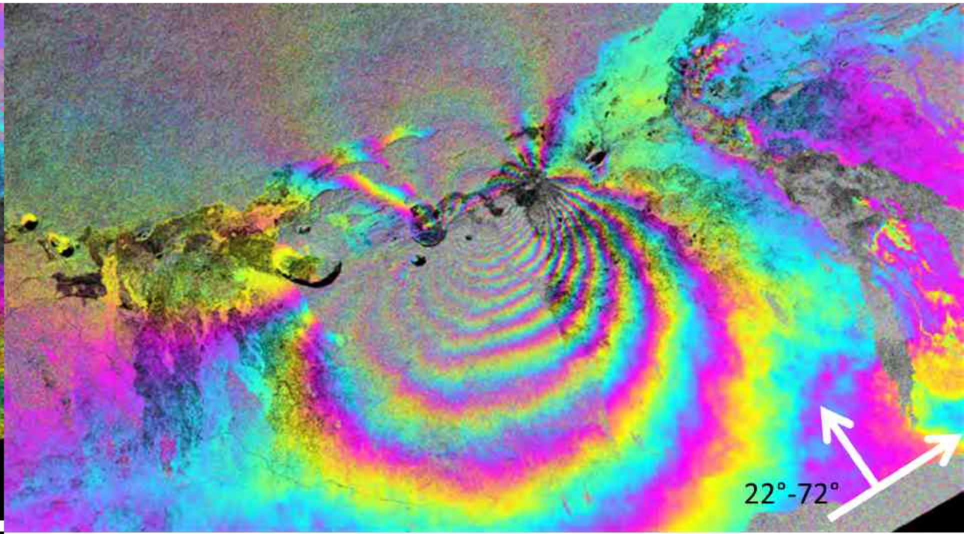
Unwrapped interferograms displayed at their natural wrap rates:
12 cm/cycle ALOS
1.5 cm/cycle TSX and CSK

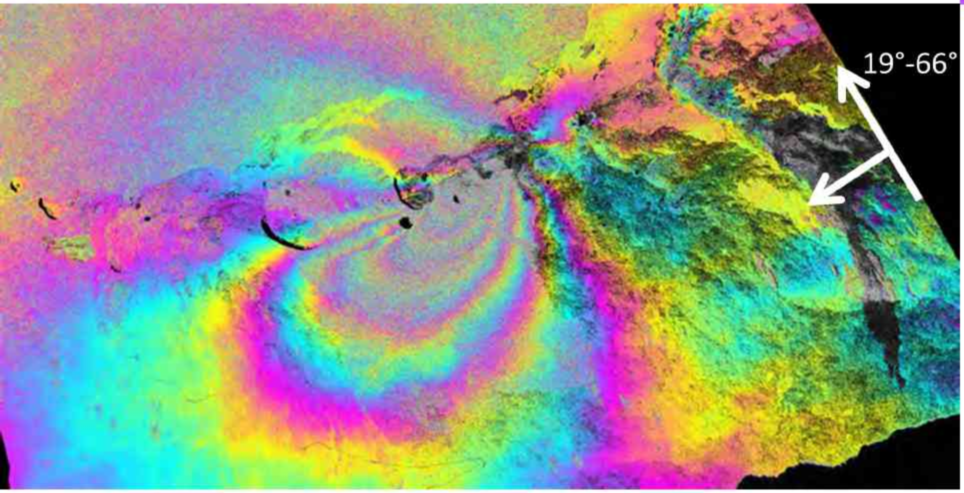


Co-eruptive satellite InSAR data used in dike modeling (with dates ending March 6-11, 2011)

UAVSAR spanning eruption



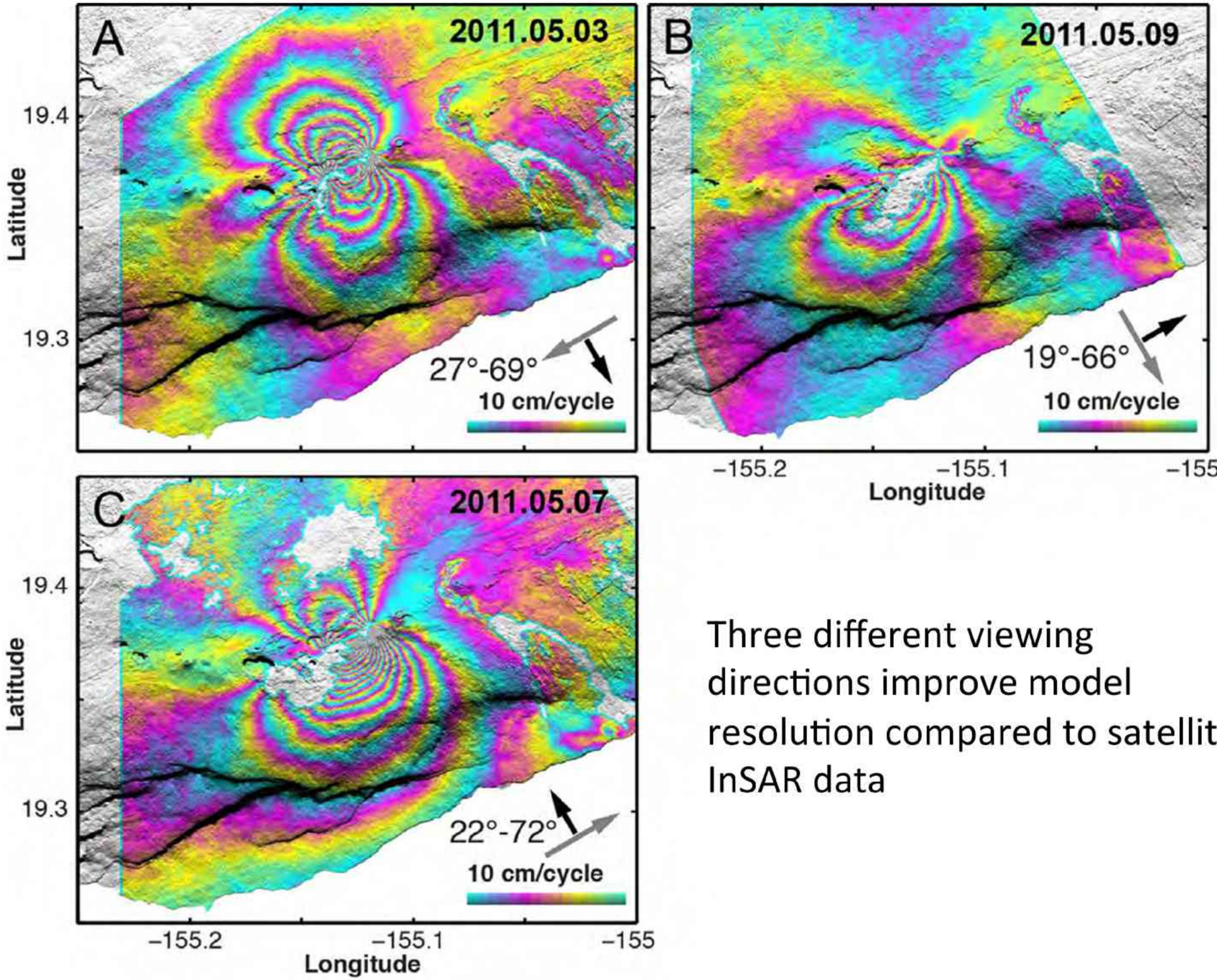




UAVSAR interferograms, (Jan 2010 – May 2011), 1.4 years, spanning the March 5-9, 2011 eruption

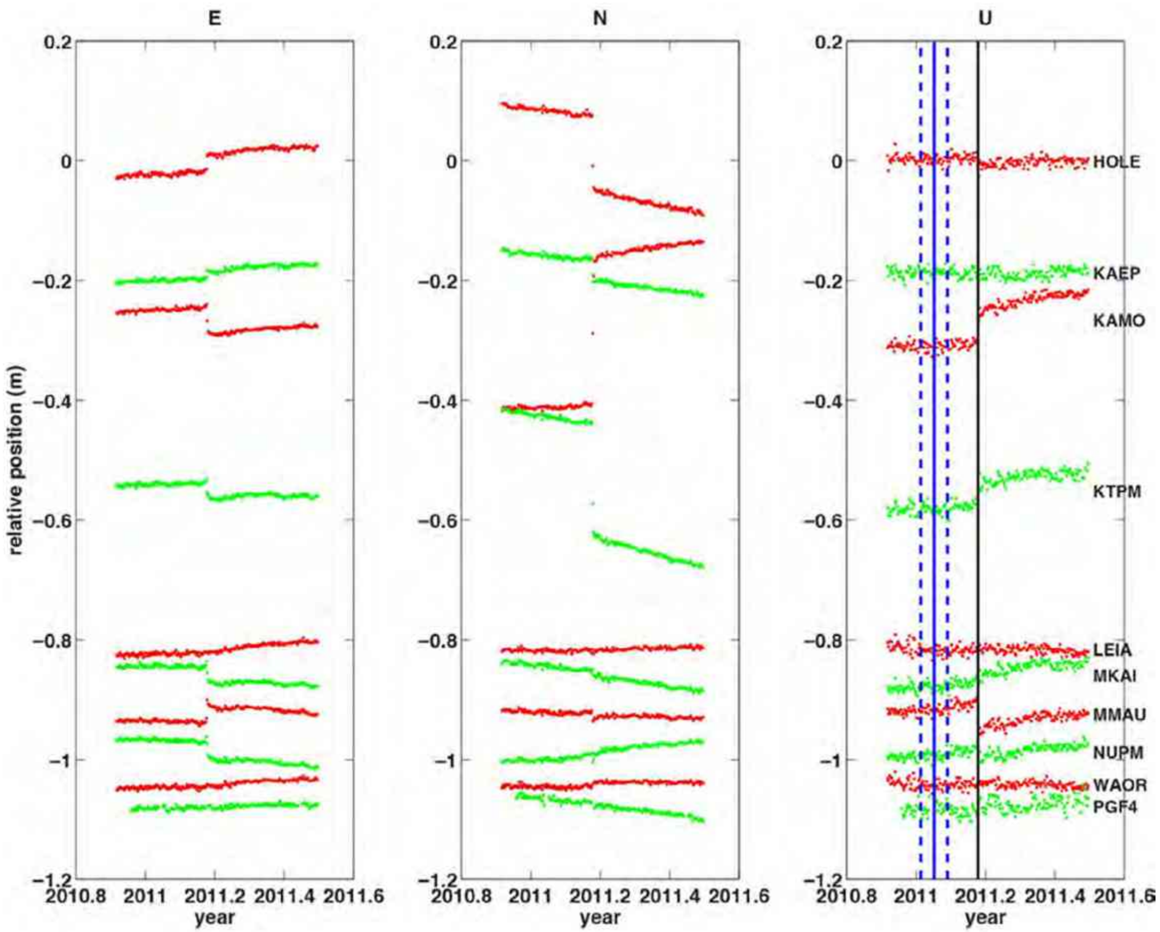
uavsar.jpl.nasa.gov for more info.

UAVSAR May 3-9, 2011



Three different viewing directions improve model resolution compared to satellite InSAR data

GPS data



GPS daily positions relative to Pacific Plate motion, from HVO.

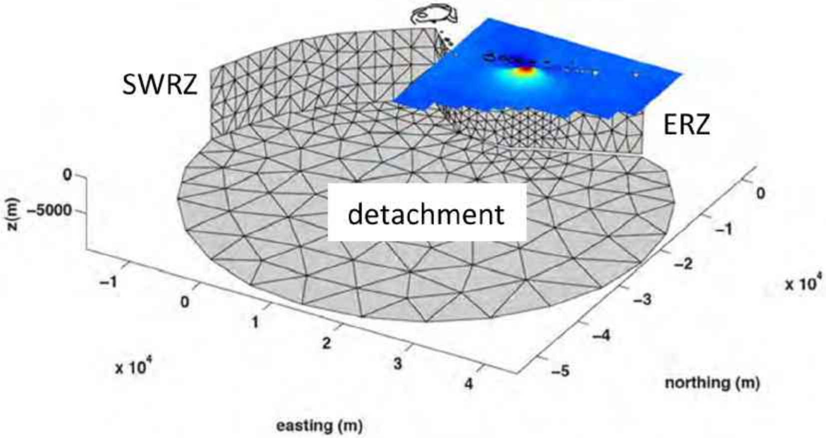
Displacements corresponding to InSAR dates computed from GPS position differences (blue and black lines).

Variances (σ^2) estimated from +- 14 day interval around starting date (blue dashed lines)

Modeling

- Bayesian MCMC approach for estimating initial dike geometry & post-diking sources
- Laplacian smoothed rift-detachment model to determine dike opening distribution
- InSAR data down-sampled using quadtree model-based approach (R. Lohman code)

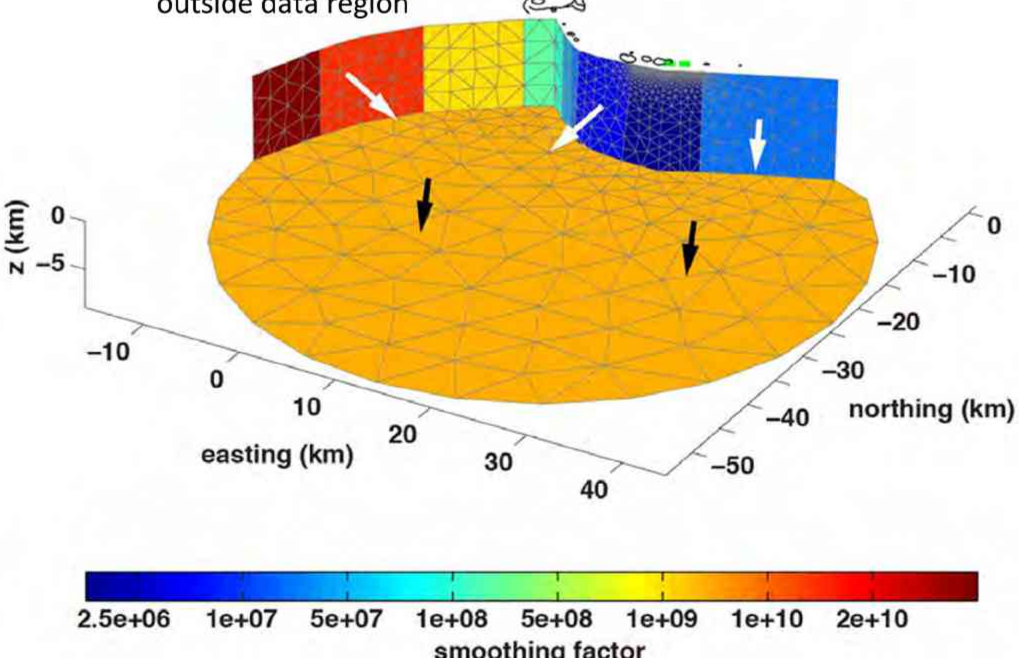
Model Setup

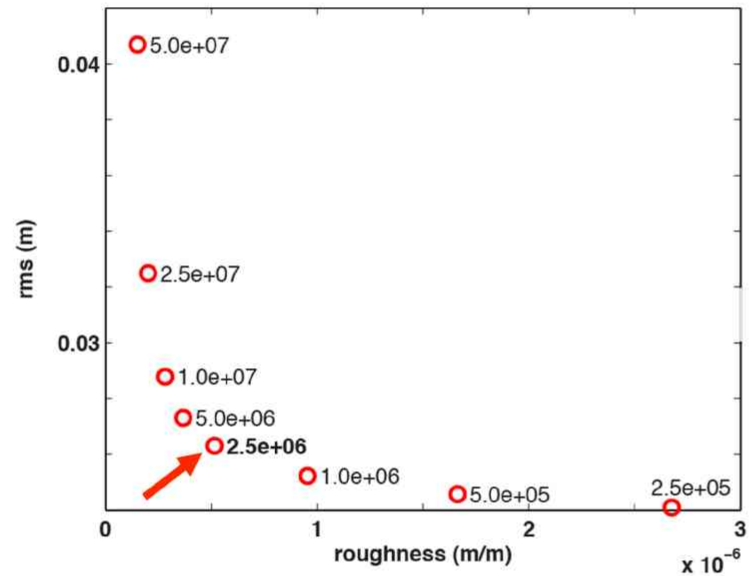


SW & E rift zones vertical except in the ERZ, triangular dislocations, tensile for rifts, dip-slip for detachment

Non-negative least squares inversion for dike opening and detachment slip

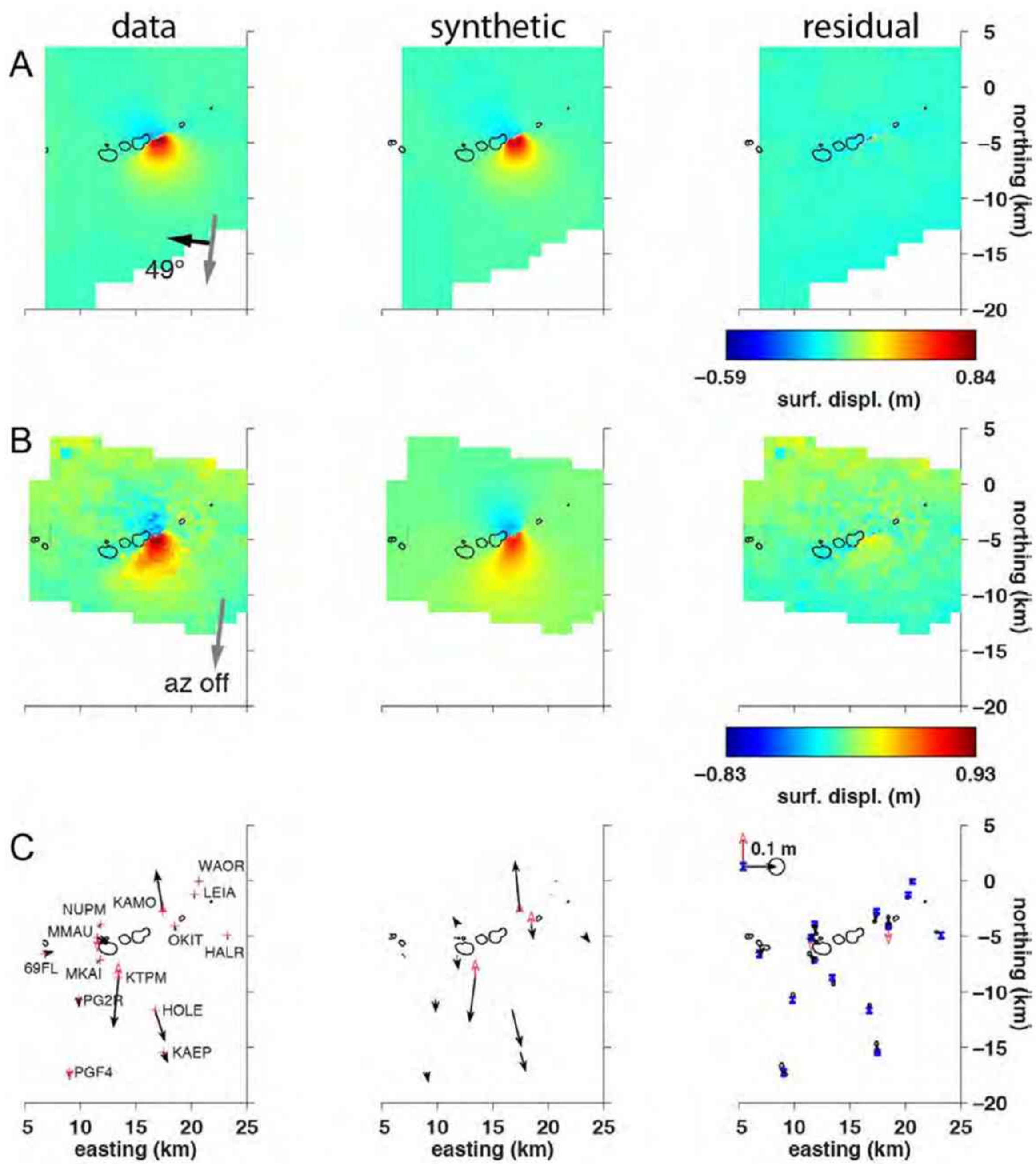
Smoothing factors vary to damp model displacements outside data region





Smoothing factor for Kamoamoa dike section chosen from L-curve "corner"

March 6

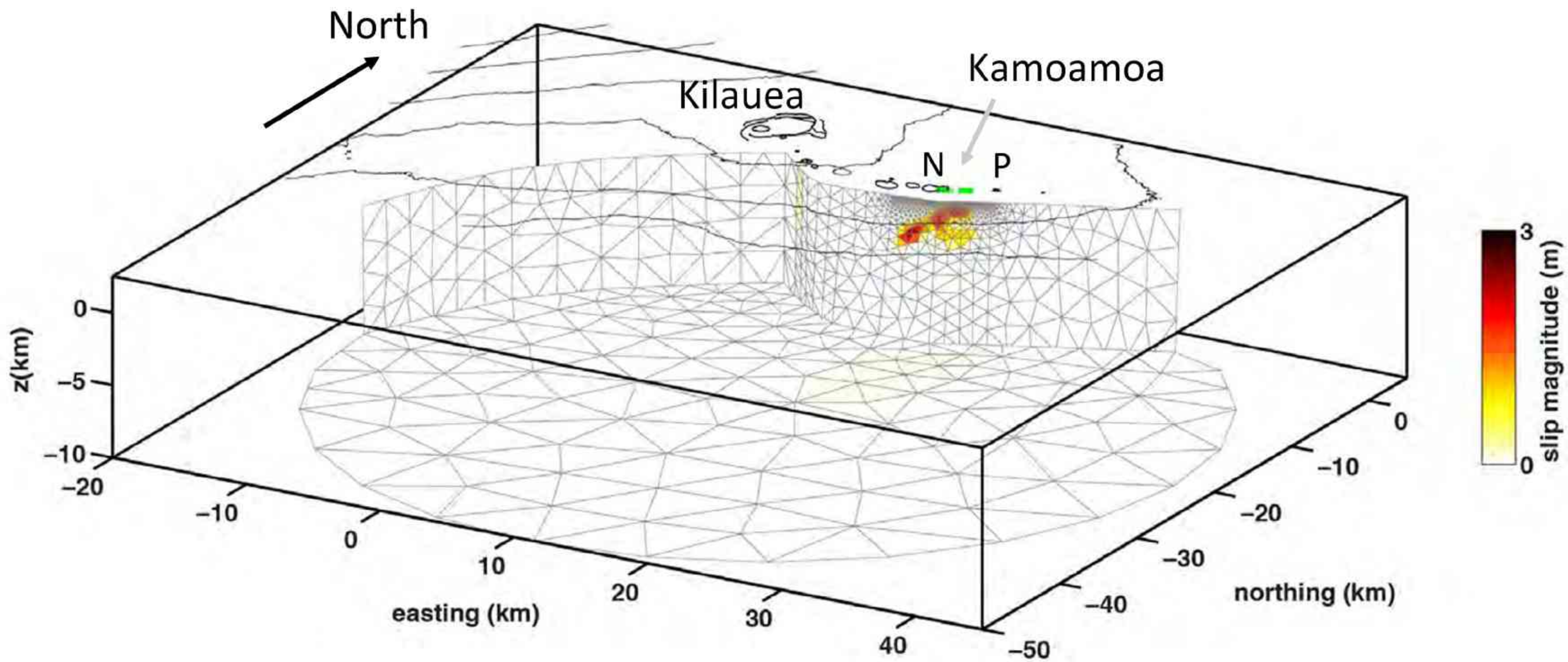


LOS surface displ.

Azimuth offsets

GPS displacements

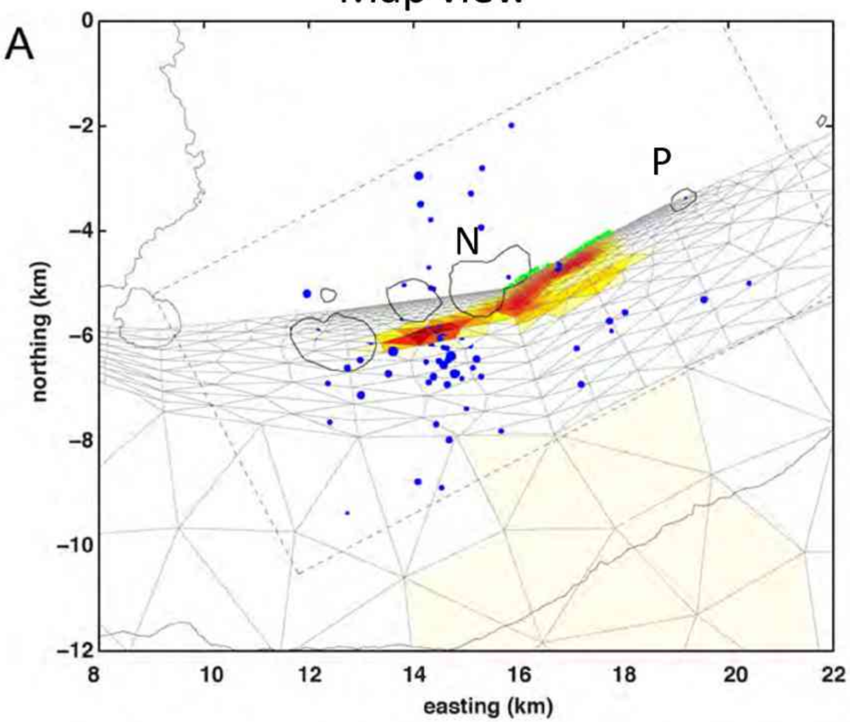
March 6 model solution



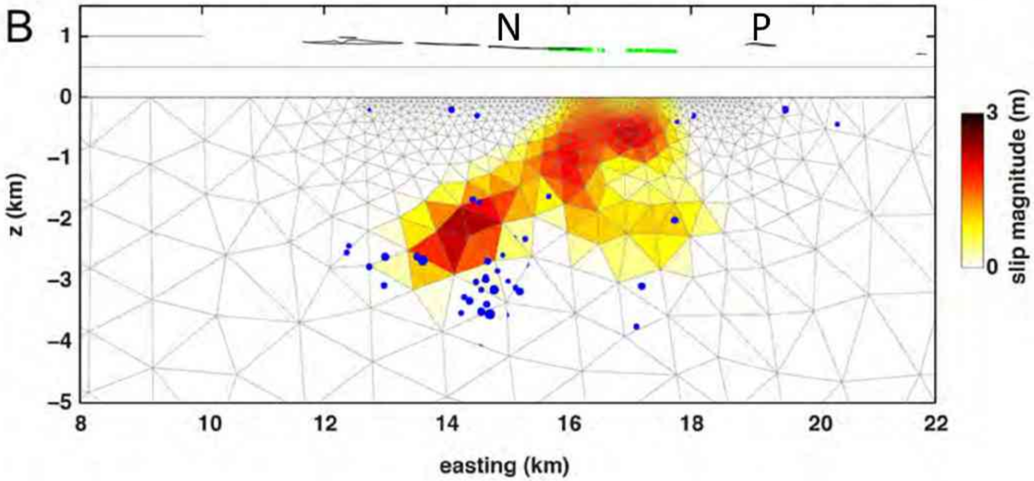
N: Napau Crater
P: Pu`u O`o Crater

March 6 model solution zoom

Map view



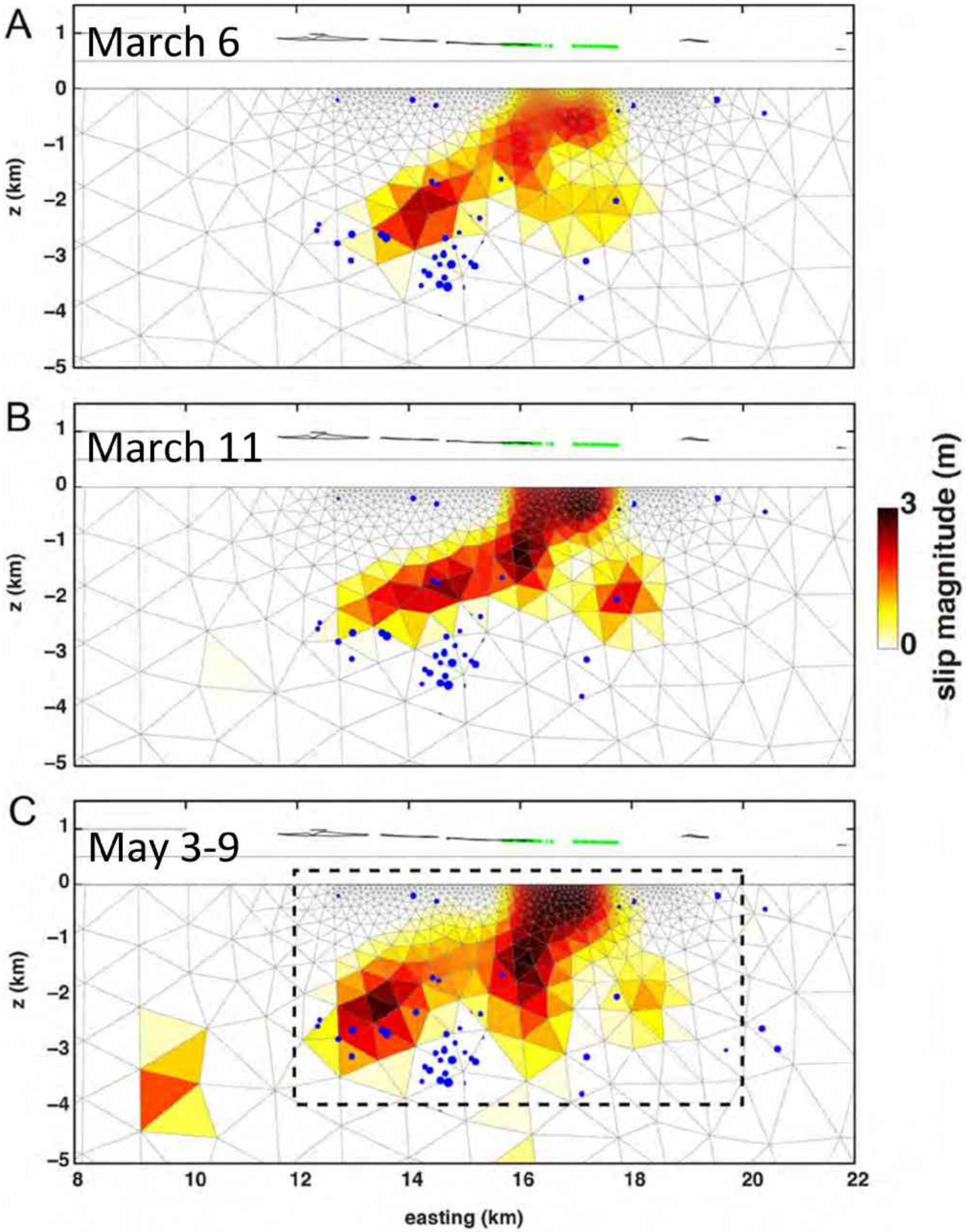
Side view from South

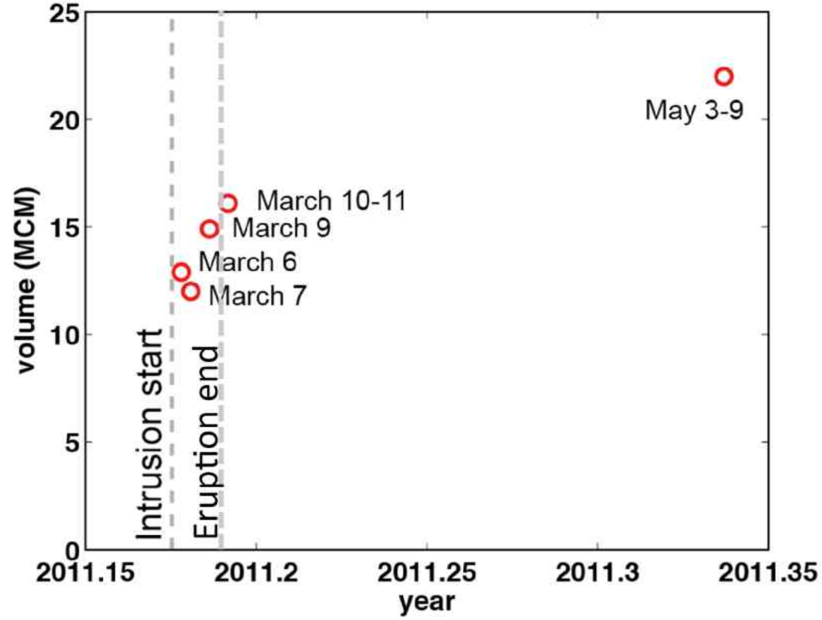


Seismicity only shown for area within dashed box, (courtesy M. Poland, HVO).

- Dike opening confined to upper 3 km
- Main portion deepens towards SW beneath Napau crater (N), with lesser extension towards Pu`u O`o crater (P).
- Max opening ~2 m (in deepest portion)

Dike opening, seismicity, and volume





Volumes

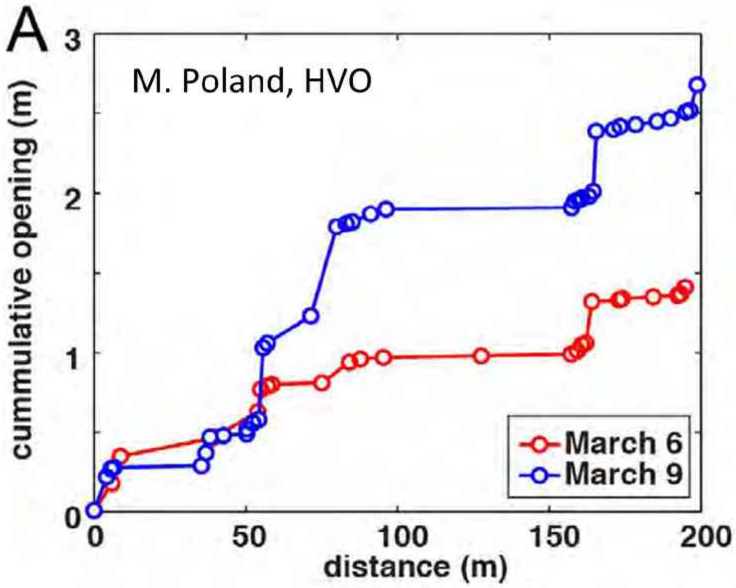
- Kilauea summit: (from InSAR+GPS model) — -1.7×10^6 m^3
- Puu Oo collapse: — -5.6×10^6 m^3
- **Total loss** — **-6.3 MCM**

- Fissure erupted March 5-9: 2.7×10^6 m^3
- Dike volume (March 11): 16.1×10^6 m^3
- **Total intruded/erupted** — **18.8 MCM**
- $r_V = 2.5$ in line w/ magma compressability range ~1.2-4.3 for Kilauea (Rivalta and Segall, 2008)

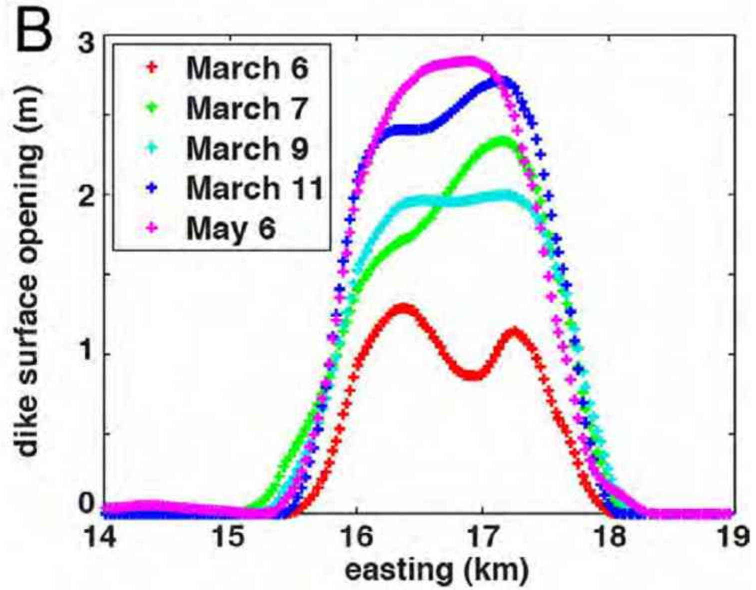
Co-eruptive surface crack and fissure opening

Dike surface opening

Field measurements across fissures



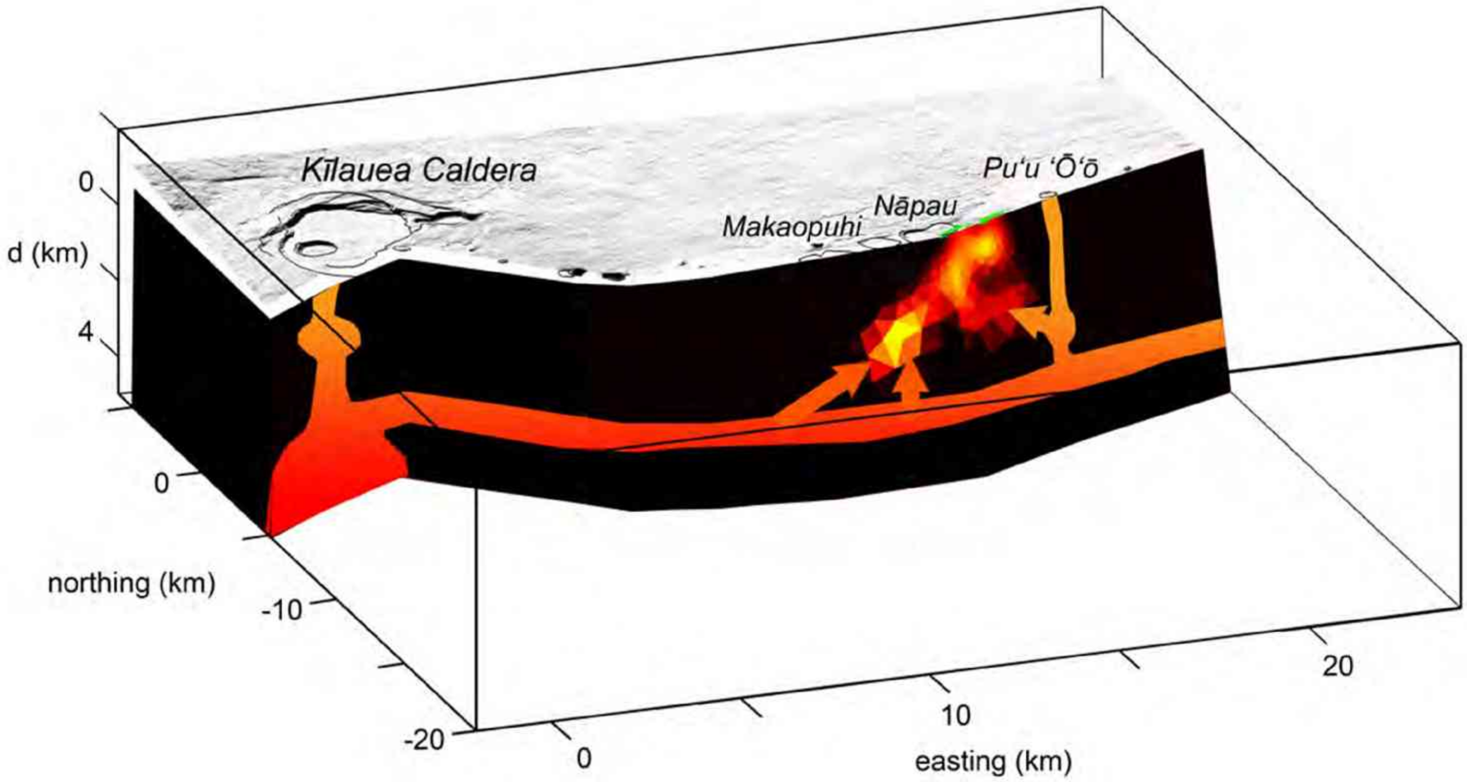
Modeled opening along top of dike



Field observations on March 6 & 9 are similar to modeled opening in top row of model elements for models of March 6 & March 11, but with the following caveats:

- HST vs UTC (dates not equal, models for March 7, 9 poorer quality)
- differences in distributed ~200 m aperture cracks vs modeled dike

Dike intrusion model summary



The March 2011 Kamoamoa dike intrusion and fissure eruption appears fed from 3 km depth beneath the surface in the up-rift (summit) direction and at about 2 km from beneath a Pu'u O'o source. Near simultaneous (30 min delay at Kilauea) tilt at the summit and Pu'u O'o suggests a well connected plumbing system.

Summary

- We continue to expand UAVSAR observations in the Pacific “Ring of Fire” in an effort to apply it to a large volcanic eruption sequence.
- March 2011 Kilauea models show a dike that plunges up-rift towards Kilauea Caldera as well as a lesser “arm” extending towards Pu’u O’o.
- Dike opening increased from ~1.5 to 3 m from early to end of eruption.
- Dike volume increased during and after the eruption,
- Ratio of dike+erupted volume/Kilauea+Pu’u ‘O’o volume loss is ~2.5, within range expected for compressible magmas.
- Dike shape and volume history have implications for dike propagation and eruption dynamics.
- The March 2011 eruption shows the importance of rapid quasi-real-time InSAR data access and short revisit times (COSMO-SkyMed) and the importance of UAVSAR (L-band) for constraining source models.

Acknowledgements: data courtesy ASI, JAXA, DLR, NASA, through eGEOS, PIXEL, Hawaii Supersite, and UAVSAR Project (Yang Zheng and flight crew), respectively.